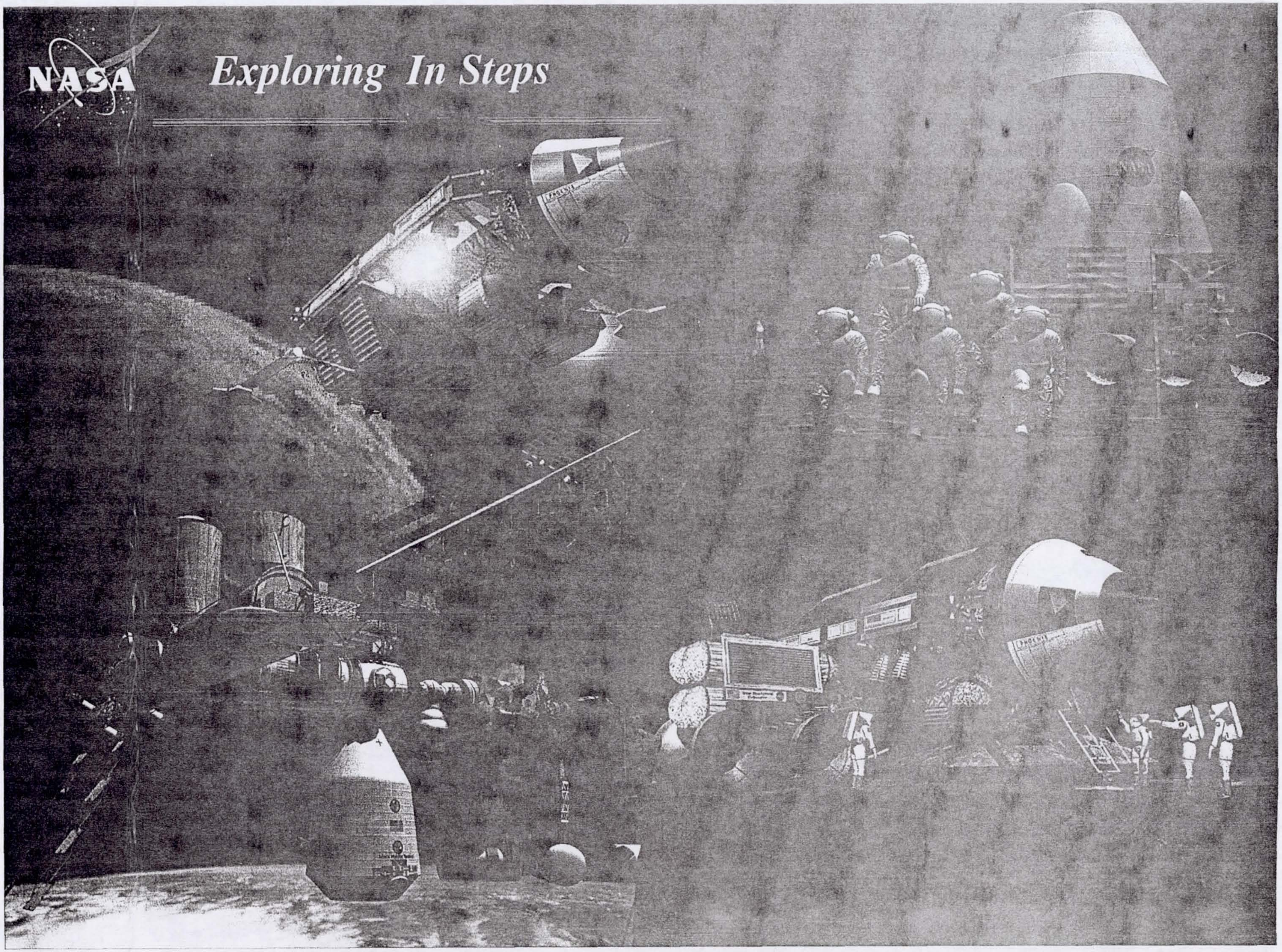
Stepping Beyond LEO

John F. Connolly

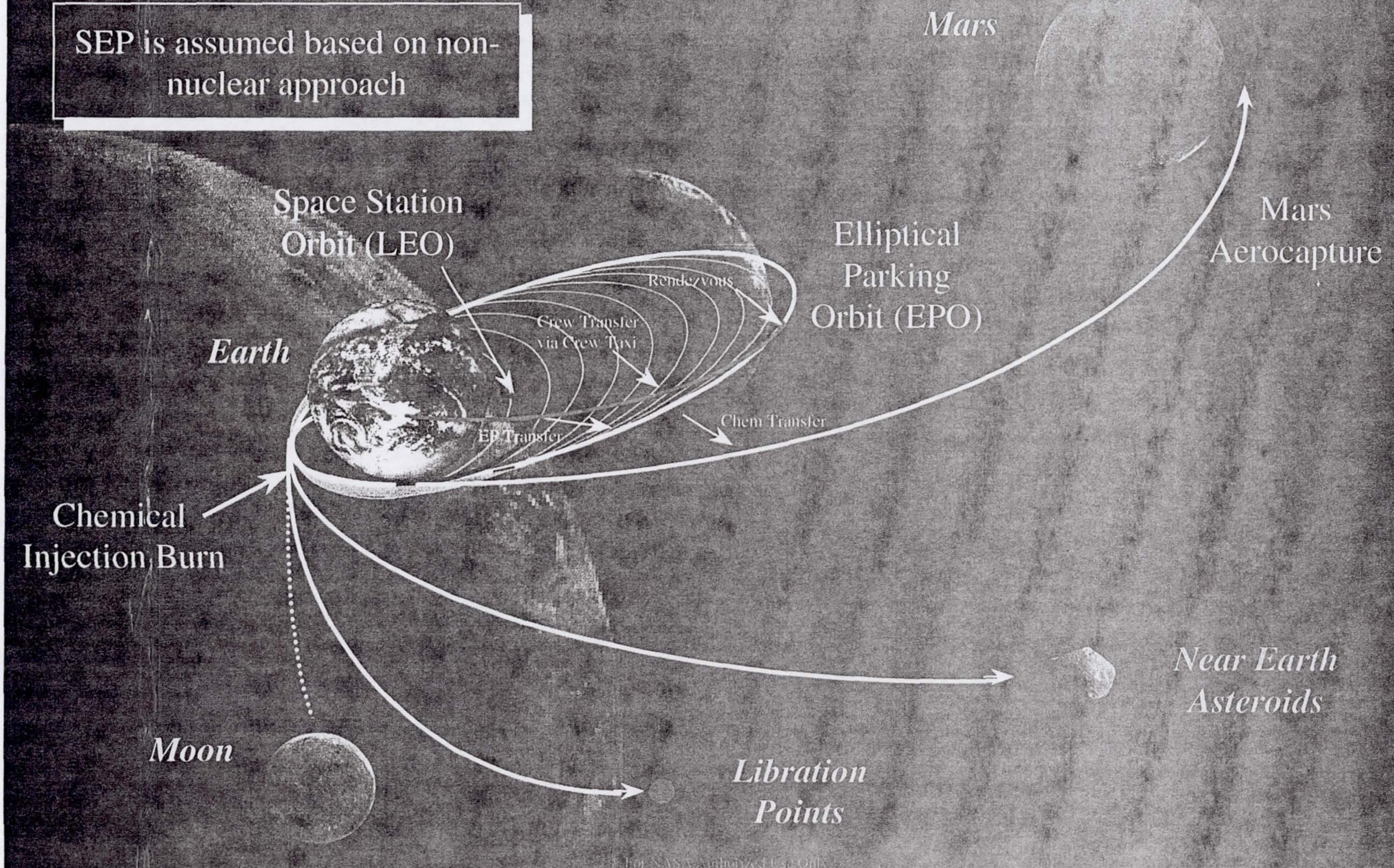
NASA/Johnson Space Center

14 June 2000


NASA
Exploring In Steps

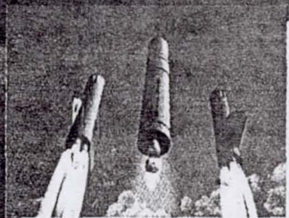
Mission Staging Scenarios

SEP is assumed based on non-nuclear approach



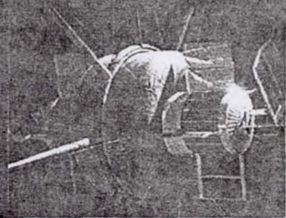
Human Exploration Common Capabilities

Earth to Orbit Transportation



- Moon (follow on)
- Asteroids
- Mars

Interplanetary Habitation

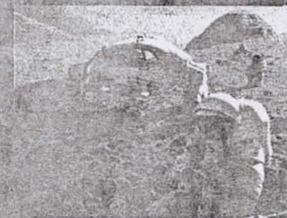


- Moon
- Sun-Earth Libration
- Asteroids
- Mars

Crew Taxi / Return

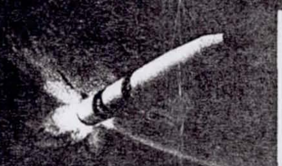
- Moon
- Sun-Earth Libration
- Asteroids
- Mars

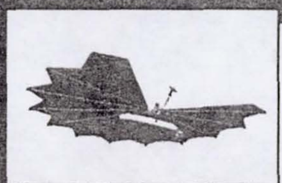
EVA & Surface Mobility



- Moon
- Mars
- Asteroids

Advanced Space Transportation Options





Advanced Chemical

"Small"
- Moon (follow on)
- Sun-Earth Libration

"Large"
- Asteroids
- Mars

Electric Propulsion

≤500 kWe
- Moon
- Sun-Earth Libration
- Mars Outpost

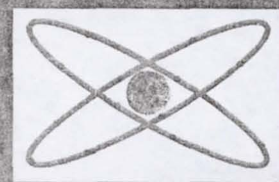
≥1 MWe
- Asteroids
- Mars

Nuclear Thermal
- Asteroids
- Mars
- Moon (follow-on)

In-Situ Resource Utilization

- Moon
- Mars

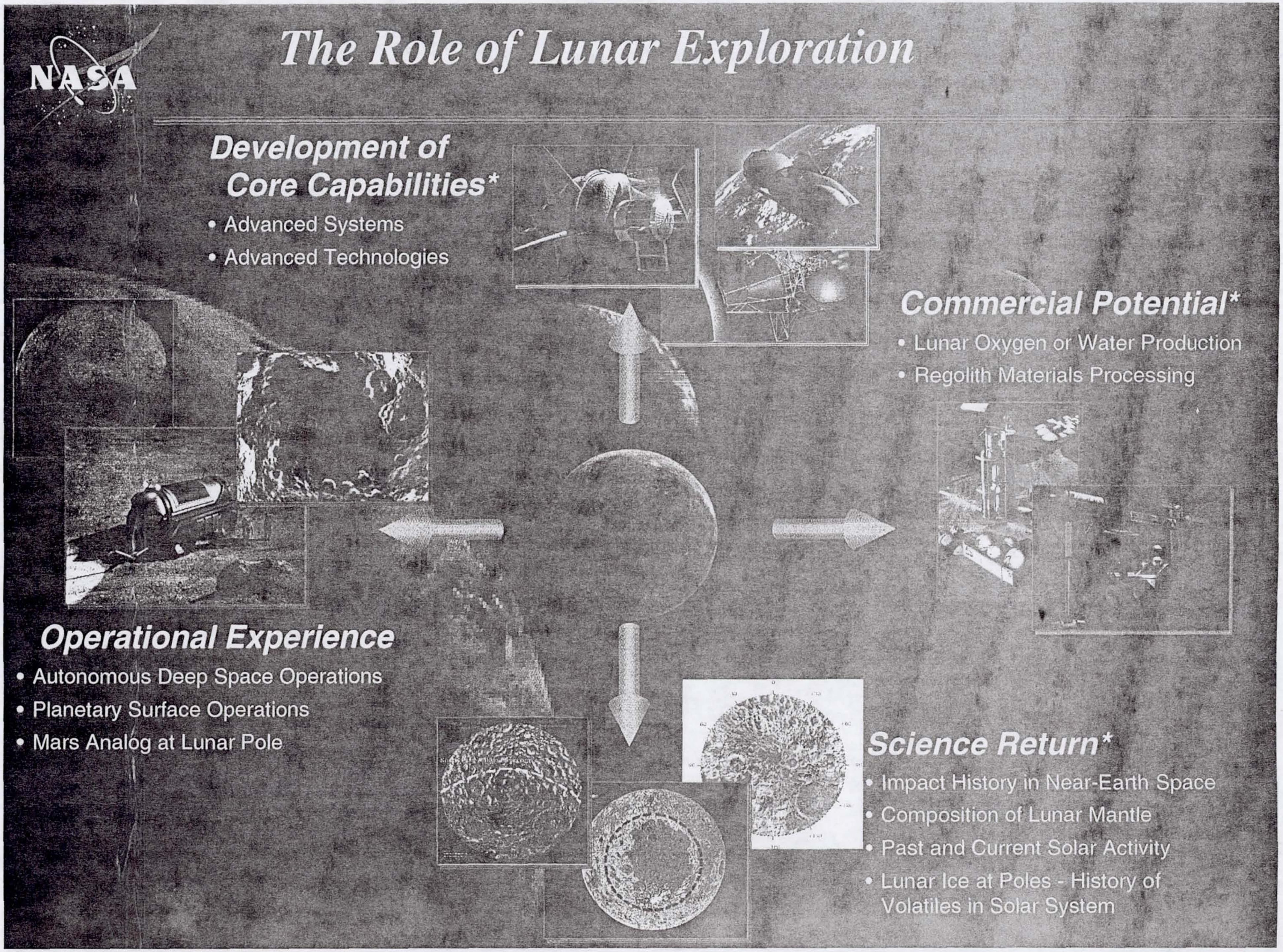
Com/Nav Infrastructure



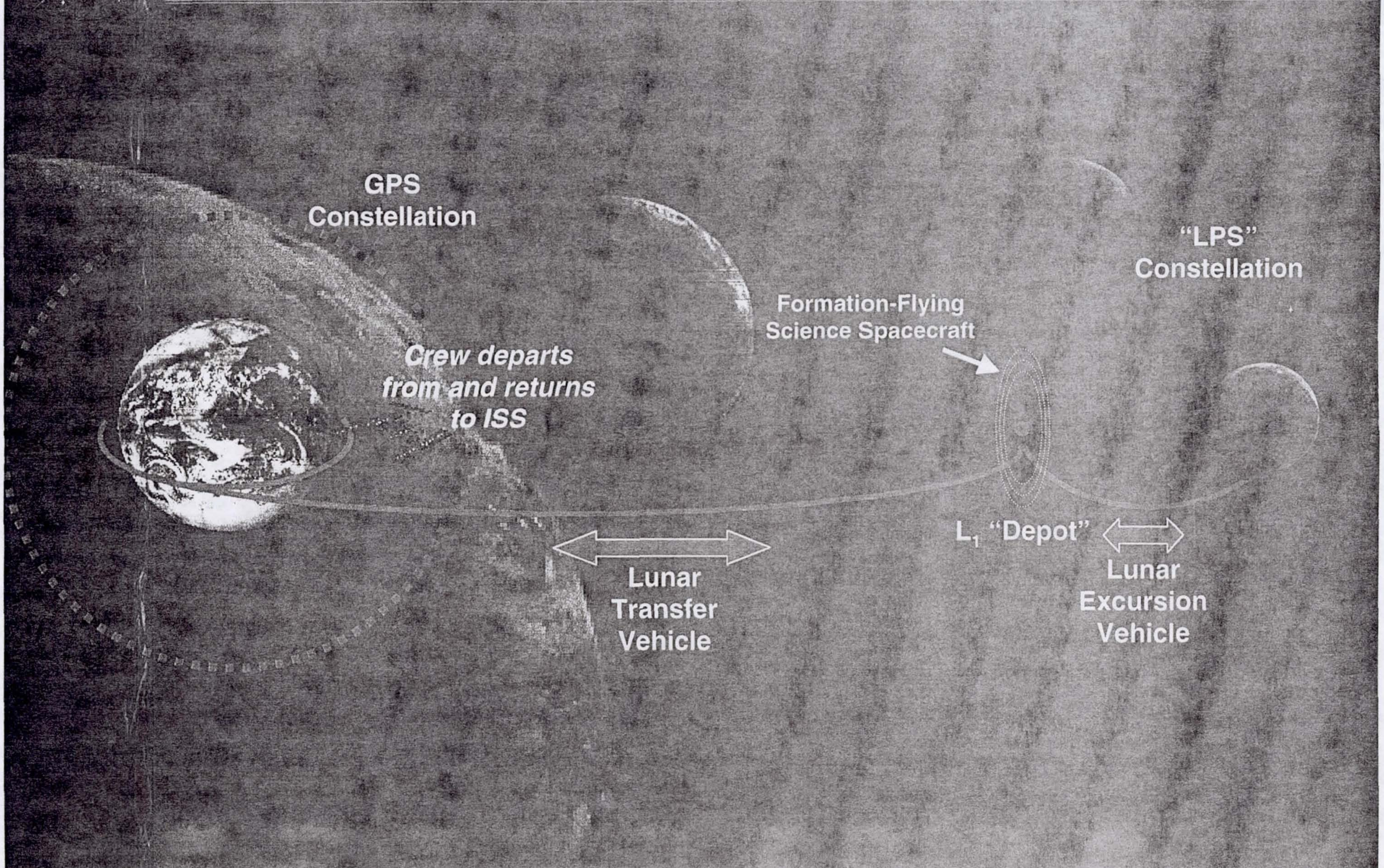
- Moon
- Mars

Representative Lunar Missions

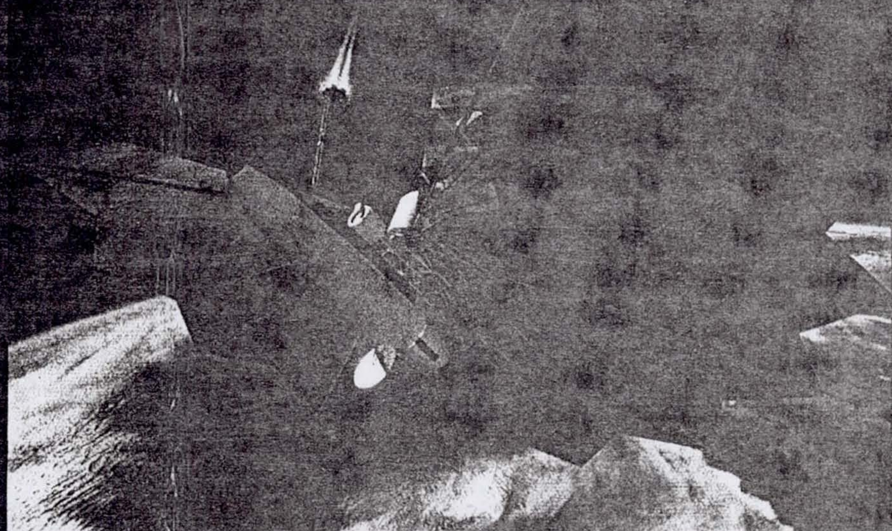
"100-Day" Class Mission


The Role of Lunar Exploration
NASA
Development of Core Capabilities*
• Advanced Systems
• Advanced Technologies
Commercial Potential*
• Lunar Oxygen or Water Production
• Regolith Materials Processing
Operational Experience
• Autonomous Deep Space Operations
• Planetary Surface Operations
• Mars Analog at Lunar Pole
Science Return*
• Impact History in Near-Earth Space
• Composition of Lunar Mantle
• Past and Current Solar Activity
• Lunar Ice at Poles - History of Volatiles in Solar System

Human Lunar Architecture Concept



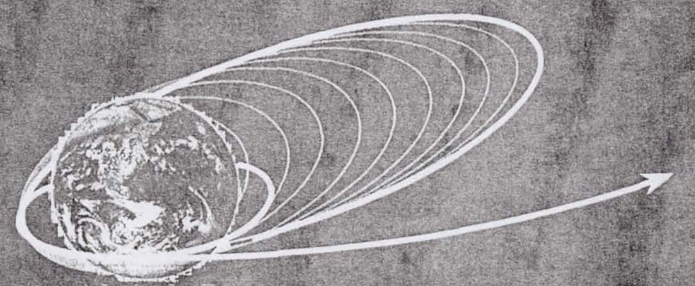
Solar Electric Propulsion Vehicle



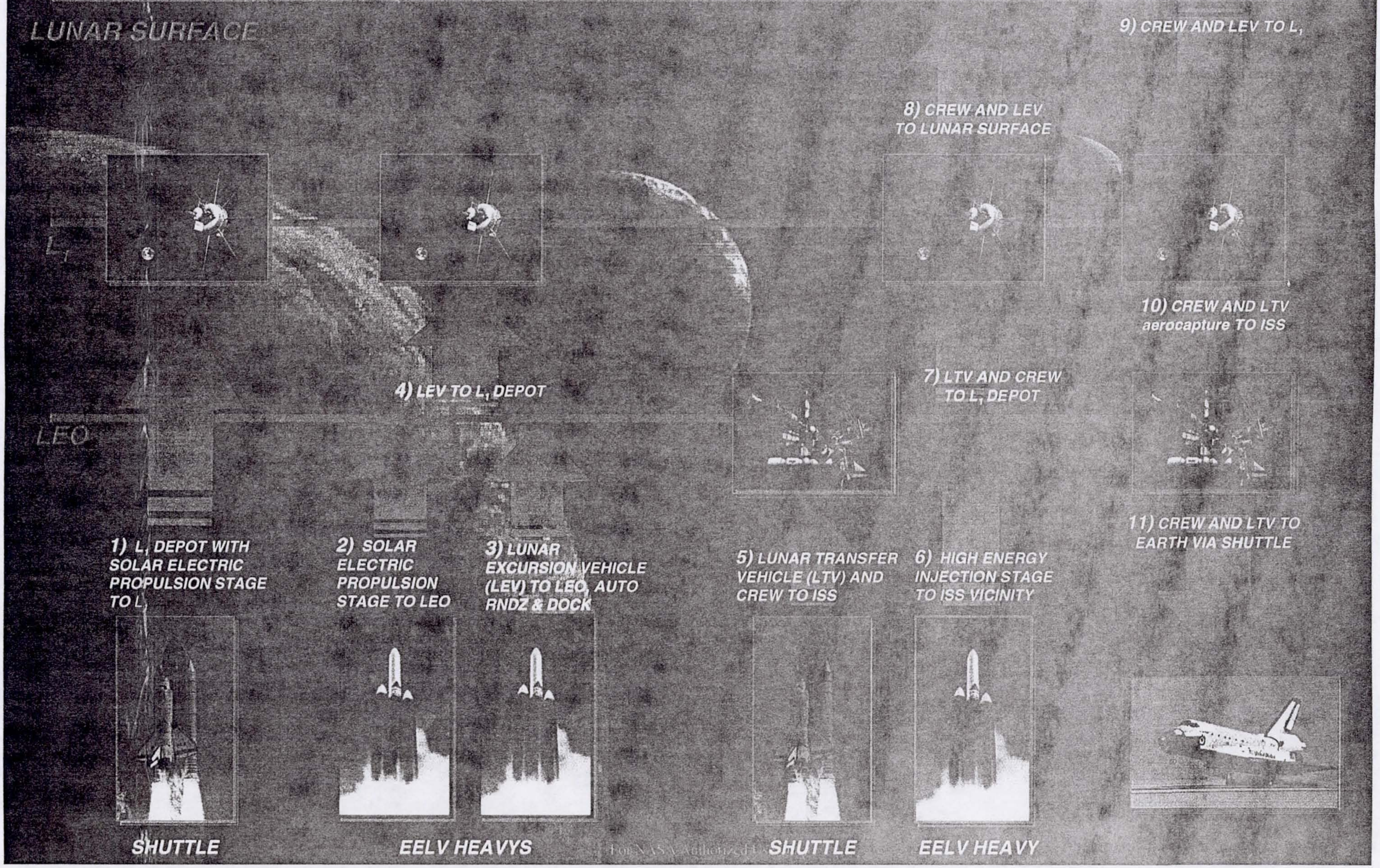
SEP 1	
Landers	203 mt
SEP Vehicle	99 mt
SEP 2	
Piloted Systems	188 mt
SEP Vehicle	99 mt
Total Mass	589 mt

Characteristics:

- Low thrust system
- High Efficiency (2500 sec Isp)
- Solar Electric Propulsion (SEP) vehicle boosts mission payload from Low-Earth Orbit (407 km) to High-Earth Orbit (120,000 km x 800 km)
- SEP vehicle returns to LEO for reuse
- Two SEP vehicles used at the same time to boost mission payloads to their departure orbits.



Lunar Mission Concept



Representative Human Missions to Near Earth Asteroids

"300" Day Class Mission

Design Reference Point: Asteroids

Near-Earth Asteroids

- Small bodies up to 40 km in diameter
- Near-Earth Asteroids orbits approach or cross the Earth's orbit

Human Exploration and Science Objectives

- Knowledge of the formation and evolution of the solar system
- Planetary history
- Resource characterization
- Potential commercial opportunities

Can provide an inexpensive and early validation of:

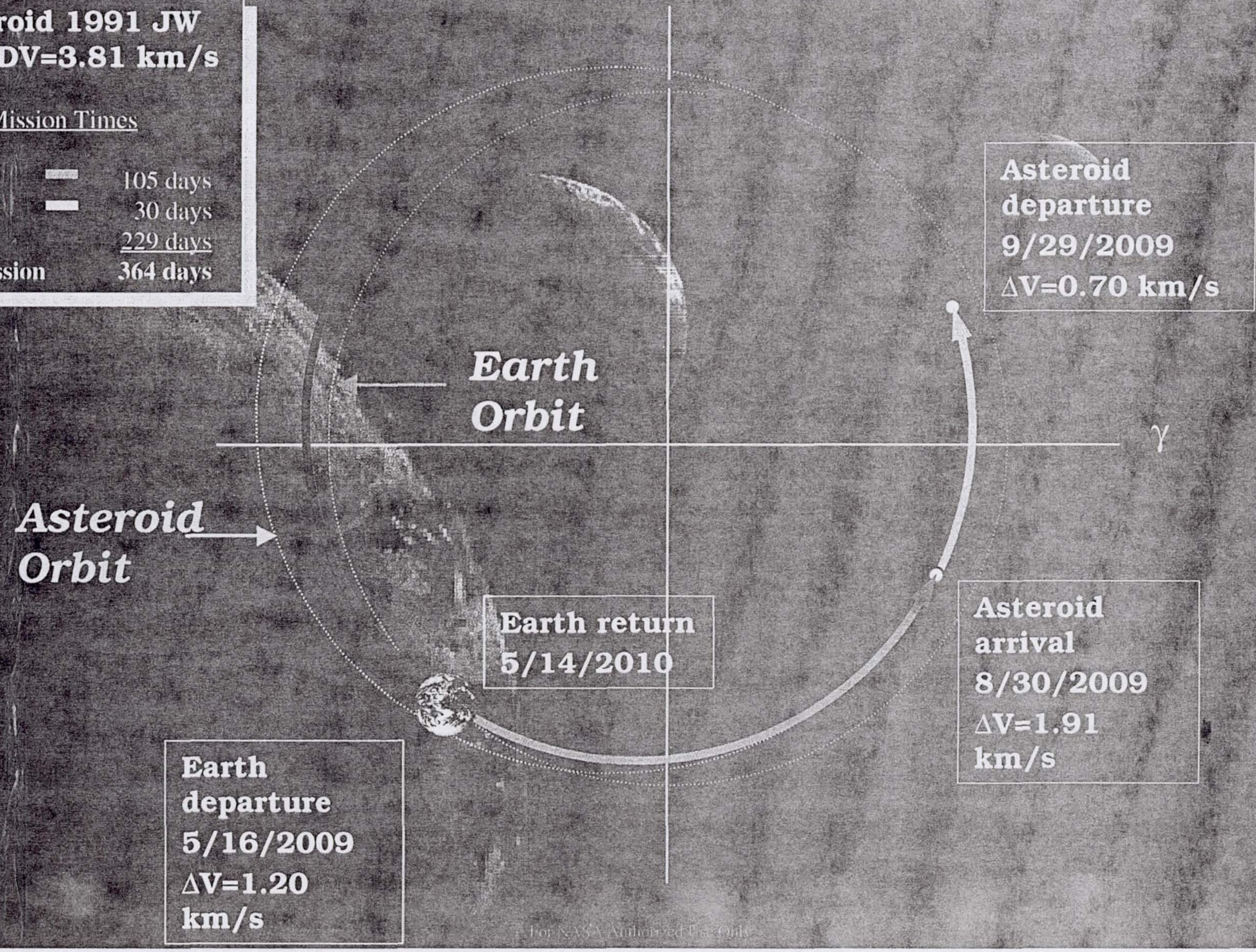
- Core exploration capabilities and technologies
- Development and demonstration of interplanetary cruise hardware
- Deep-space operational experience

An Example Asteroid Mission Profile

Asteroid 1991 JW
Total DV=3.81 km/s

Mission Times

Outbound	105 days
Stay	30 days
Return	229 days
Total Mission	**364 days**



Candidate Near-Earth Asteroids

Asteroid Designation	Diameter (m)	Synodic Period (yrs)	Departure Date	Trip Time (Days)				Total ΔV (m/s) **
				Outbound	Stay	Inbound	Total	
1991 JW	330-750	18.38	05/16/2009	105	30	229	**364**	3803
1991 JW	330-750	18.38	05/18/2027	112	30	220	**362**	2783
1991 VG*	5-12	25.53	07/31/2016	237	30	109	**376**	2091
1997 XR2	170-380	9.5	12/04/2015	248	30	97	**375**	4843
1997 YM9	25-60	7.86	06/23/2005	228	30	110	**368**	3732
1997 YM9	25-60	7.86	06/24/2013	216	30	121	**367**	3730
1997 YM9	25-60	7.86	06/24/2021	207	30	132	**369**	3893
1997 YM9	25-60	7.86	06/27/2029	191	30	144	**365**	4067
1998 KG3	85-190	4.98	04/21/2017	256	30	89	**375**	5538
1998 KG3	85-190	4.98	04/26/2012	254	30	91	**375**	5850
1998 KG3	85-190	4.98	04/16/2022	257	30	88	**375**	5276
1998 KG3	85-190	4.98	04/12/2027	257	30	88	**375**	5096
1998 VO	220-500	9.85	11/09/2007	257	30	84	**371**	5496
1999 AO10	44-100	6.75	07/31/2005	143	30	198	**371**	4144
1999 AO10	44-100	6.75	09/09/2011	248	30	97	**375**	5747
1999 AO10	44-100	6.75	08/16/2018	228	30	117	**375**	4679
1999 CG9	24-54	11.77	01/29/2011	93	30	252	**375**	4697
1999 CG9	24-54	11.77	07/26/2022	104	30	241	**375**	3627
1999 JU3	320-720	4.37	06/04/2007	190	30	145	**365**	5702
1999 AO10	44-100	6.75	08/04/2025	201	30	144	**375**	3939
1999 CG9	24-54	11.77	08/05/2010	84	30	86	**200**	3826
1999 CG9	24-54	11.77	07/24/2022	69	30	101	**200**	5747
1997 YM9	25-60	7.86	12/17/2005	57	30	105	**192**	4609

One-Year Round-Trip Missions (first 20 rows)

Six-Month Round-Trip Missions (last 3 rows)

* Believed to be the Apollo 8 Saturn V third stage

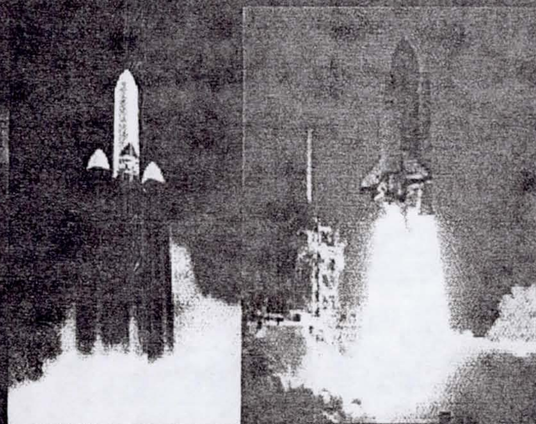
** Performance estimates from 120,550 x 800 km high Earth departure orbit

Repeat launch opportunities range from once every [illegible] to 18 years

Human Asteroid Mission Sequence

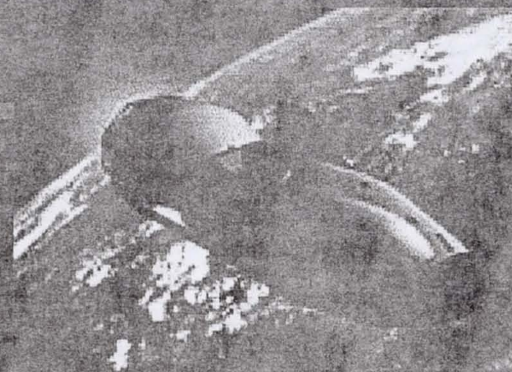
(Solar Electric Propulsion Vehicle Option)

High Earth Orbit Boost Phase



1) Launch of Transit Vehicle into Low earth Orbit

2) SEP vehicle boosts Transit Vehicle to High Earth Orbit

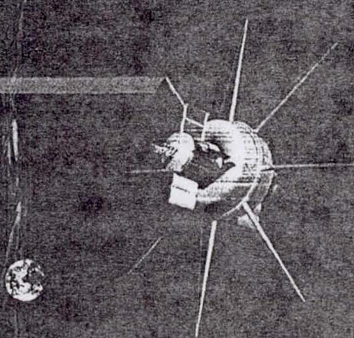


3) Crew Taxi takes Crew to Transit Vehicle in High Earth Orbit

A

Transit - Asteroid Operations - And Return

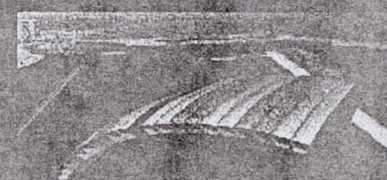
A



4) Trans-Asteroid Injection

5) Coast Phase (90-260 days depending on opportunity)

6) Asteroid Operations
- Rendezvous
- Approach Sequence
- Surface Operations



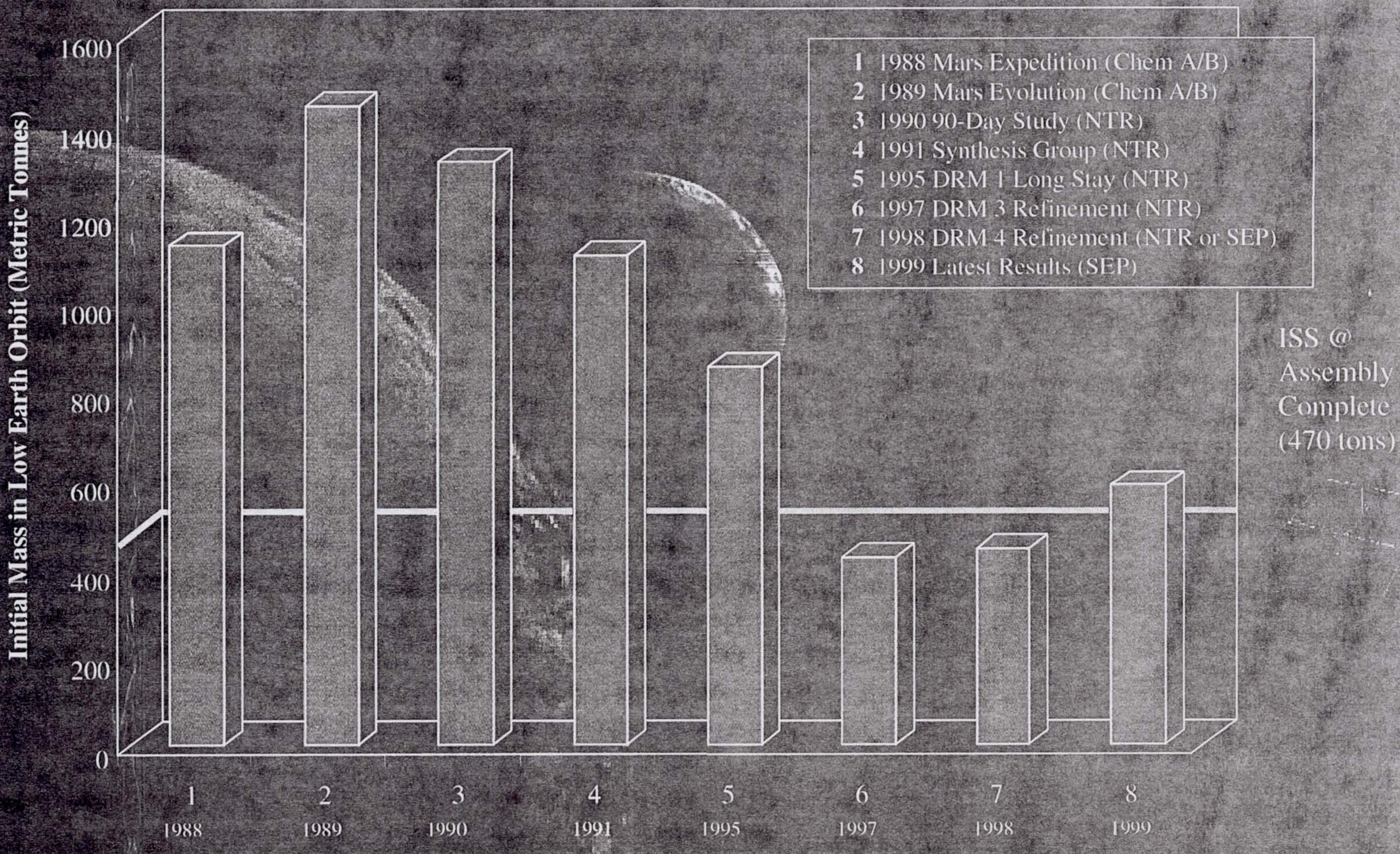
7) Direct Earth Entry at End of Mission

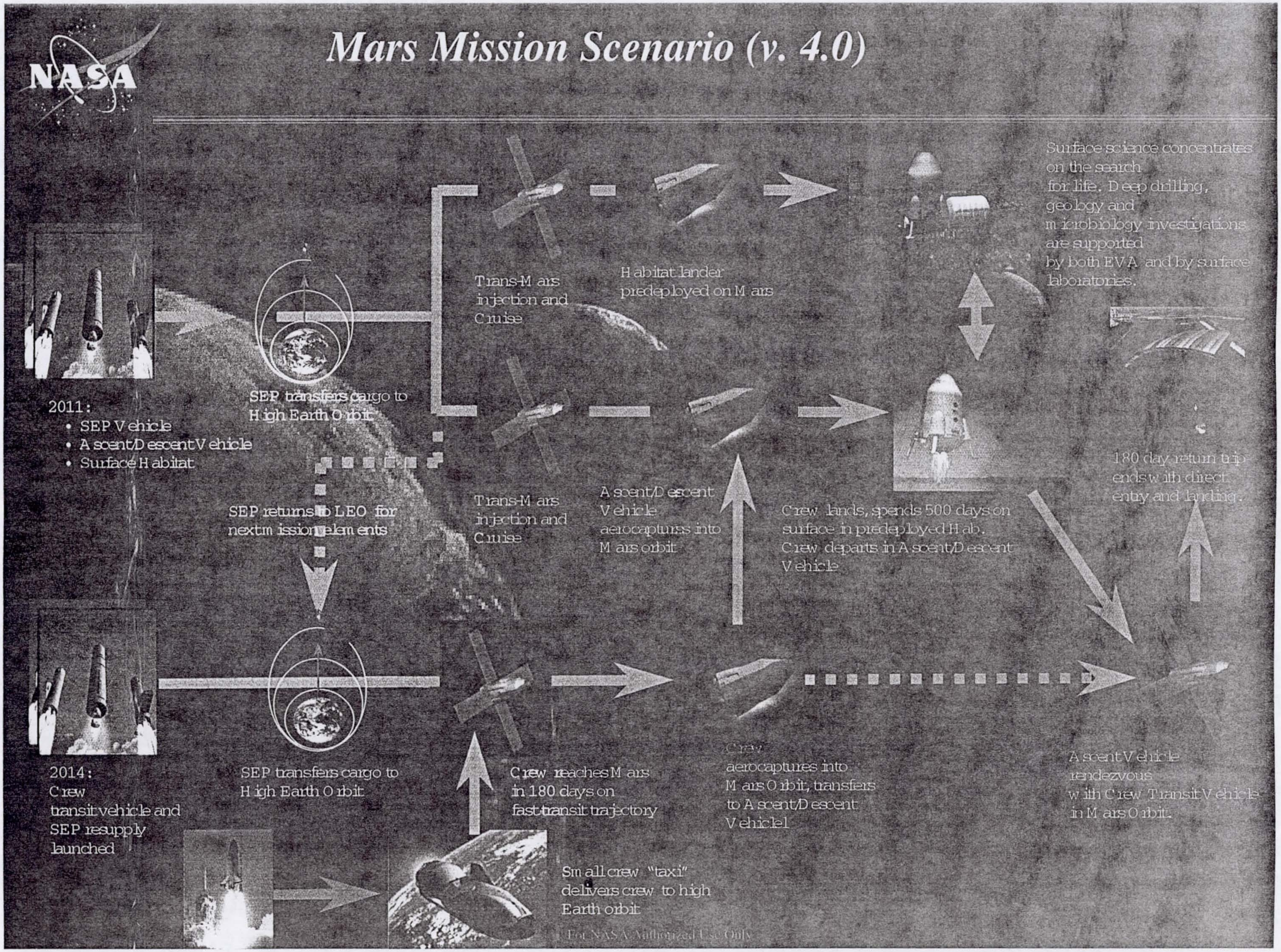
NASA

Representative Human Missions to Mars

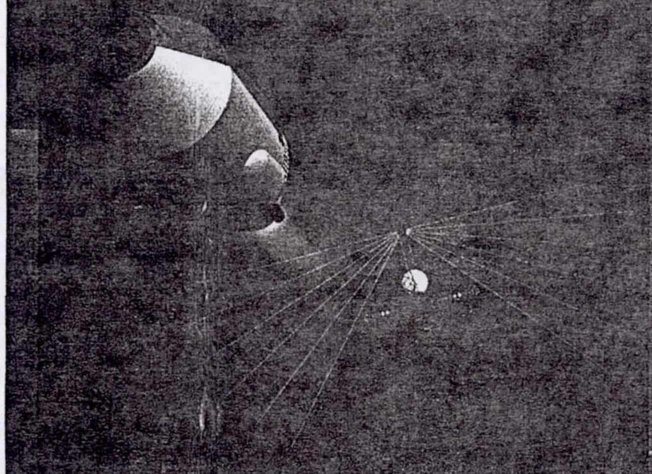
"1000" Day Class Mission

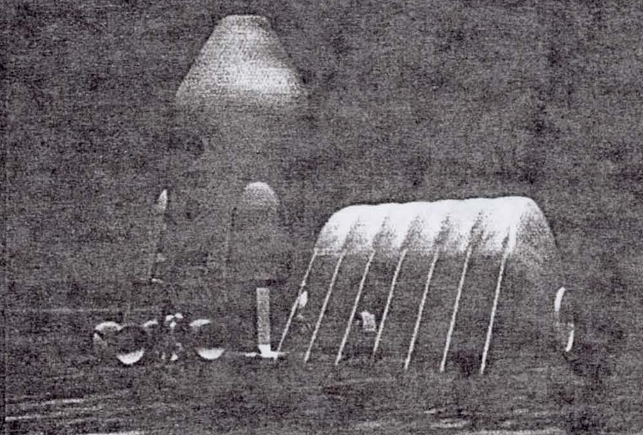
Mars Architecture Mass Comparison

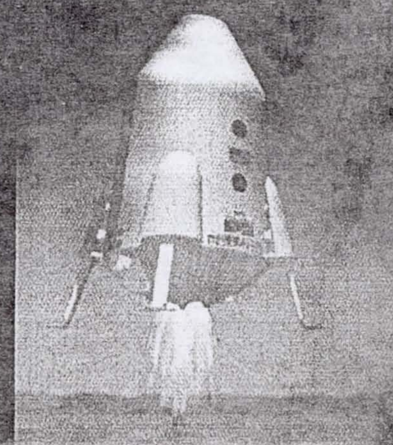



NASA
Mars Mission Scenario (v. 4.0)
2011:
• SEP Vehicle
• Ascent/Descent Vehicle
• Surface Habitat
SEP transfers cargo to High Earth Orbit
SEP returns to LEO for next mission elements
Trans-Mars injection and Cruise
Habitat lander predeployed on Mars
Trans-Mars injection and Cruise
Ascent/Descent Vehicle aerocaptures into Mars orbit
Surface science concentrates on the search for life. Deep drilling, geology and microbiology investigations are supported by both EVA and by surface laboratories.
Crew lands, spends 500 days on surface in predeployed Hab. Crew departs in Ascent/Descent Vehicle
180 day return trip ends with direct entry and landing.
2014:
Crew transit vehicle and SEP resupply launched
SEP transfers cargo to High Earth Orbit
Crew reaches Mars in 180 days on fast-transit trajectory
Crew aerocaptures into Mars Orbit, transfers to Ascent/Descent Vehicle1
Ascent Vehicle rendezvous with Crew Transit Vehicle in Mars Orbit.
Small crew "taxi" delivers crew to high Earth orbit
For NASA Authorized Use Only

Mars Mission Vehicles







Mars Transit Vehicle

- Supports mission crew of six for up to 200-day transits to and from Mars
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI
- Total Vehicle Mass in High-Earth Orbit = 188 mt

Mars Surface Habitat

- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg
- Total Vehicle Mass in High-Earth Orbit = 99 mt

Descent/Ascent Vehicle

- Transports six crew from Mars orbit to the surface and back to orbit
- Provides contingency abort-to-orbit capability
- Supports six crew for 30-days
- Vehicle capable of utilizing locally produced propellants
- Total Vehicle Mass in High-Earth Orbit = 103 mt

Supporting Critical Technologies

Human Research & Technologies

- Radiation research and protection
- Zero/low-gravity research and countermeasures
- Regenerable closed-loop life support
- Advanced medical care and diagnostics

Propulsion Technologies

- Efficient in-space propulsion
  - Electric/Plasma
  - Nuclear Thermal
  - Advanced Chemical
- Low-cost, high efficiency engines
- Long-term cryogenic fluid management

Robust/Efficient Power Systems

- Generation, management, and storage
- Stationary and mobile

Flight Technologies

- High-speed aerocapture
- Automated Rendezvous and Docking
- Guided entry and precision landing/hazard avoidance

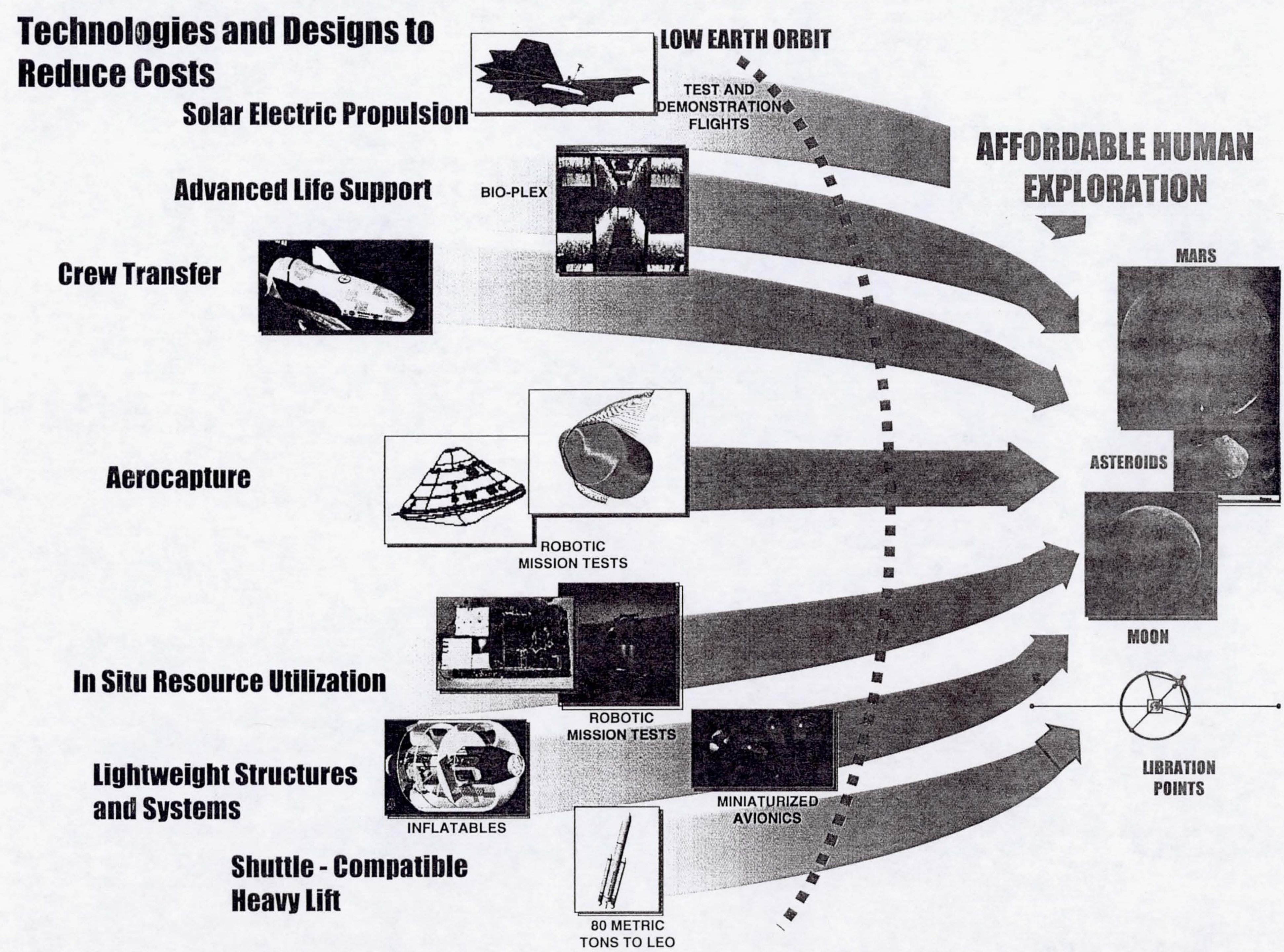
Information & Automation

- Advanced automation
- Information technologies
- High rate communications and data transfer

Lightweight Structures, Systems, Sensors

- Light-weight materials
- Micro/nano electronics

Sample Curation


Technologies and Designs to Reduce Costs
Solar Electric Propulsion
LOW EARTH ORBIT
TEST AND DEMONSTRATION FLIGHTS
AFFORDABLE HUMAN EXPLORATION
Advanced Life Support
BIO-PLEX
Crew Transfer
MARS
Aerocapture
ASTEROIDS
ROBOTIC MISSION TESTS
MOON
In Situ Resource Utilization
ROBOTIC MISSION TESTS
Lightweight Structures and Systems
INFLATABLES
MINIATURIZED AVIONICS
LIBRATION POINTS
Shuttle - Compatible Heavy Lift
80 METRIC TONS TO LEO

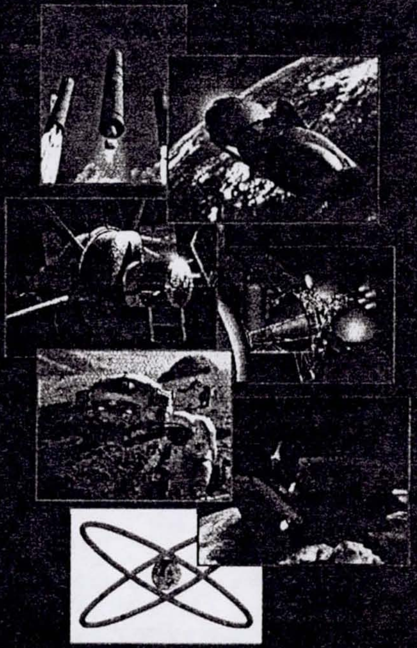
Core Capabilities & Technologies

Common Technology Building Blocks (Core Technologies)	*Common System Building Blocks (Core Capabilities)*	*Potential Destinations*

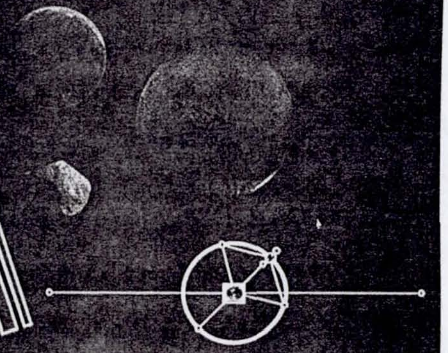
Examples

- Efficient In-Space Prop..
- Aeroassist
- Low-cost Engines
- Cryo Fluid Management
- Robust/Efficient Power
- Lightweight structures
- Radiation Research
- Zero/Low-g Research
- Regenerable Life Support
- Advanced Lightweight EVA

System Design



Mission Analyses



- "Breakthrough" Technologies